COMPARISON TEST PROGRAM
LIQUID FLOW MEASUREMENT FINAL RESULTS
CENAM - PTB - NIST

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Abstract

This comparison-test program (1997/1998) **CENAM - PTB - NIST** was in order to assess the Mexican primary standard for liquid flow measurement. This program was initiated by CENAM to establish and maintain satisfactory liquid flow measurement in Mexico. In the future this program could be expanded to the international flow measurement community to include other Latin America laboratories.

The estimated uncertainty for CENAM's volumetric flow rate facility is nearly constant over the range of 300 L/min to 2 100 L/min (± 0,12 % with a coverage factor k=2). We expected that the results differences among NIST, PTB and CENAM were inside CENAM's uncertainty limits, however the test results from the first phase of the comparison denoted that K factor differences were bigger than the ones we expected.

The three national laboratories use the gravimetric technique. The test results of this comparison program are presented graphically.

1. Introduction

The liquid flow facilities at the Centro Nacional de Metrología (CENAM) constitute Mexico's primary standard for liquid flow measurements.

This primary fluid flow system not only serves as a basis for the national chain of treaceability but also as an important facility for fluid flow research. The staff of Flow and Volume Division at CENAM spent nearly the whole 1997 in doing tests for different possible arrangements that assuring stable and completely developed velocity profiles to establish the chain of traceability in Mexico.

CENAM initiated in 1997 a comparison program with the Physikalisch Technische Bundesanstalt (PTB) and the National Institute of Standards and Technology (NIST). Also, among Latin-America national standards laboratories to which this program will be extended.

Considering the fact that Mexico is a main petroleum producer, and 50 % of the output is consumed internally, it follows that its domestic market is substantial and needs accurate custody transfer metering systems.

Measurement assurance programs will to provide confidence in the results of the liquid flow measurements' techniques. To evaluate the systematic errors for CENAM's liquid flow laboratory we used the comparison program because all the procedures, components of the system, and people are evaluated entire.

2. Objectives

The main objective of the intercomparison program is to achieve international traceability in liquid flow measurements:

- To establish realistic traceability of liquid flow measurement,
- To estimate the uncertainty of the laboratory and routine procedures, and
- To confidence.

3. Test Program

Petroleos Mexicanos (PEMEX) supplied two turbine meters of 75 mm (3 inches), ANSI 300, model K2BDB00110, SN ND 201**367-G** and ND201**370-G**. Those turbine meters have been used to conduct the comparison program.

Both turbine meters were calibrated in tandem configuration -- series -- in Mexican National Laboratory. Turbine meters tandem "artifact" shown in figure 1.

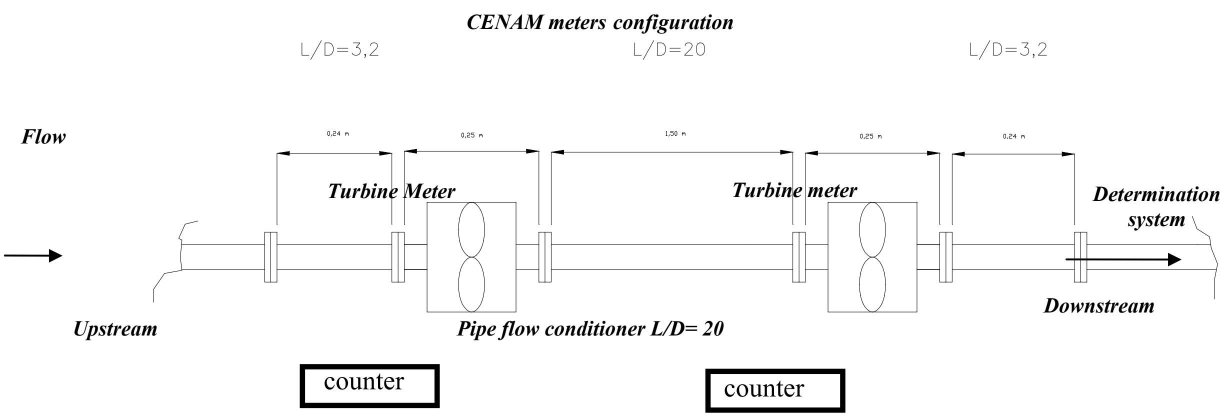


Figure 1. *Test configuration*

A test program takes into account:

1. High confidence in the fluid flow meter -- NIST and PTB high confidence laboratories.
2. The data base generate is adequate for the comparison, and
3. The national laboratories use the Guide to the Expression of Uncertainty in measurements for processing the data generated and the analysis of results.
4. All of the results are produced with routinely procedures in each laboratory.

The number of flow rates ranges from 3 to 10 as number of runs does. Each test is repeated 2 to 3 times.

Each meter should be tested in each tandem position (upstream and downstream) for each of the flow rates. Then, meter factor is calculated for each meter.

The generated data in the comparison program is analyzed with the averaged meter factors for each flow rate selected and includes the fluid conditions and the meter location in the facility.

K factor versus qv

The common way to present the data of turbine meters is the K factor as a function of volumetric flow rate or Reynolds number.

$$\mathrm{K} = \frac{pulses}{V} \ \text{(pulses/L)} \tag{1}$$

Where:

pulses- number de pulses
V- volume (L)

K factor average ($\bar{K}$)

$$\bar{K} = \frac{\Sigma_{i=1}^{n} Ki}{n} \tag{2}$$

Where n is the number of data.

The percentage deviation (E).

$$E = \frac{K_{CENAM} - \bar{\mathrm{K}}_{PTB}}{\bar{\mathrm{K}}_{PTB}} 100\,\% \quad \text{and} \quad E = \frac{K_{CENAM} - \bar{\mathrm{K}}_{NIST}}{\bar{\mathrm{K}}_{NIST}} 100\,\% \tag{3}$$

Once the intercomparison is done, both meters have to be tested at CENAM's facility so that it is confirmed that meters are running properly.

Graphical Analysis of Test Results

Youden Plots are a graphical technique for analyzing interlab data when each laboratory has made two runs on the same process measurements.

The Youden plot is a simple method for comparing both the within laboratory variability and the between laboratory variability.

The advantage of using Youden Analysis is its ability to separate random and systematic errors. An error that is purely systematic will fall on the 45-degree line. The
Youden plot was used to answer the following questions:

- Are all laboratories equivalent?
- If CENAM Liquid flow facility has between – lab problems.
- If CENAM Liquid flow facility has within labs problems.
- If CENAM Liquid flow facility is outlaiers.

The Youden analysis was performed by drawing vertical and horizontal lines, respectively, trough the PTB and NIST medians of the abscissa and ordinate data. Only two flow rates were used to test the artifact and the data analysis.

The total variation in the data were categorized by calculating standard deviations based upon the parallel and perpendicular projections of all the data points onto a line drawn through the median intersection with a slope of +1. These were:

Systematic:

$$\sigma_S = \left[\frac{1}{n-1} \sum_{i=1}^{n} P_i^2 \right]^{1/2} \quad (4)$$

Random:

$$\sigma_S = \left[\frac{1}{n-1} \sum_{i=1}^{n} N_i^2 \right]^{1/2} \quad (5)$$

Results

Table 1. The percentage deviation (E). Second phase.

Deviation (E %)					
qv (L/min)	*Test configuration I*		**qv** (L/min)	*Test configuration II*	
CENAM / PTB	**367 G**	**370G**		**367 G**	**370G**
295	**-0,04**	**-0,03**	296	**-0,05**	**-0,06**
776	**-0,04**	**0,01**	748	**-0,05**	**-0,07**
1 258	**-0,08**	**0,02**	1 237	**-0,04**	**-0,05**
1 513	**-0,08**	**0,04**	1 514	**0,00**	**-0,04**
1 758	**-0,07**	**0,03**	1 758	**0,02**	**-0,07**
CENAM / NIST	**367 G**	**370G**		**367 G**	**370G**
302	**0,00**	**0,06**	297	**0,02**	**0,02**
1 728	**-0,08**	**0,00**	1 751	**-0,18**	**-0,24**
2 065	**-0,01**	**0,05**	2 074	**-0,05**	**-0,08**

1. The tests results-- before and after -- denoted that 370 G turbine meter change it's meter K factor. However, over a period of time, this turbine meter has been calibrated once again and showed that the condition of the flow meter is adequate. A summary of test data is shown in table 2 and table 3.

2. The final -- after -- results showed that for configurations I and II the turbine 370 G had maximum differences of -0,24 % when located on upstream position. Moreover, the results -- before and after -- showed that for configuration I the turbine 367 G showed differences between - 0,08 % to 0,0 % when located upstream position.

3. Test configuration II showed maximum differences for the turbine 367 G of –0,18 % when located downstream. The results are graphed in pages 7 and 9.

4. Youden´s analysis shows that CENAM´s Laboratory had problems with repeatability and reproducibility on the initial phase of the comparison.

5. A systematic error in calibration time was detected. CENAM´s Laboratory looses pulses for a period of approximately 0,16 s.

Discussion

In general, Youden´s plot shows that:

1. The first phase of comparison showed that CENAM´s liquid flow facility was located outside from the reference value (NIST-PTB data were used as the reference on the Youden diagram).

2. The second phase showed that CENAM´s liquid flow facility was in good agreement with the reference values.

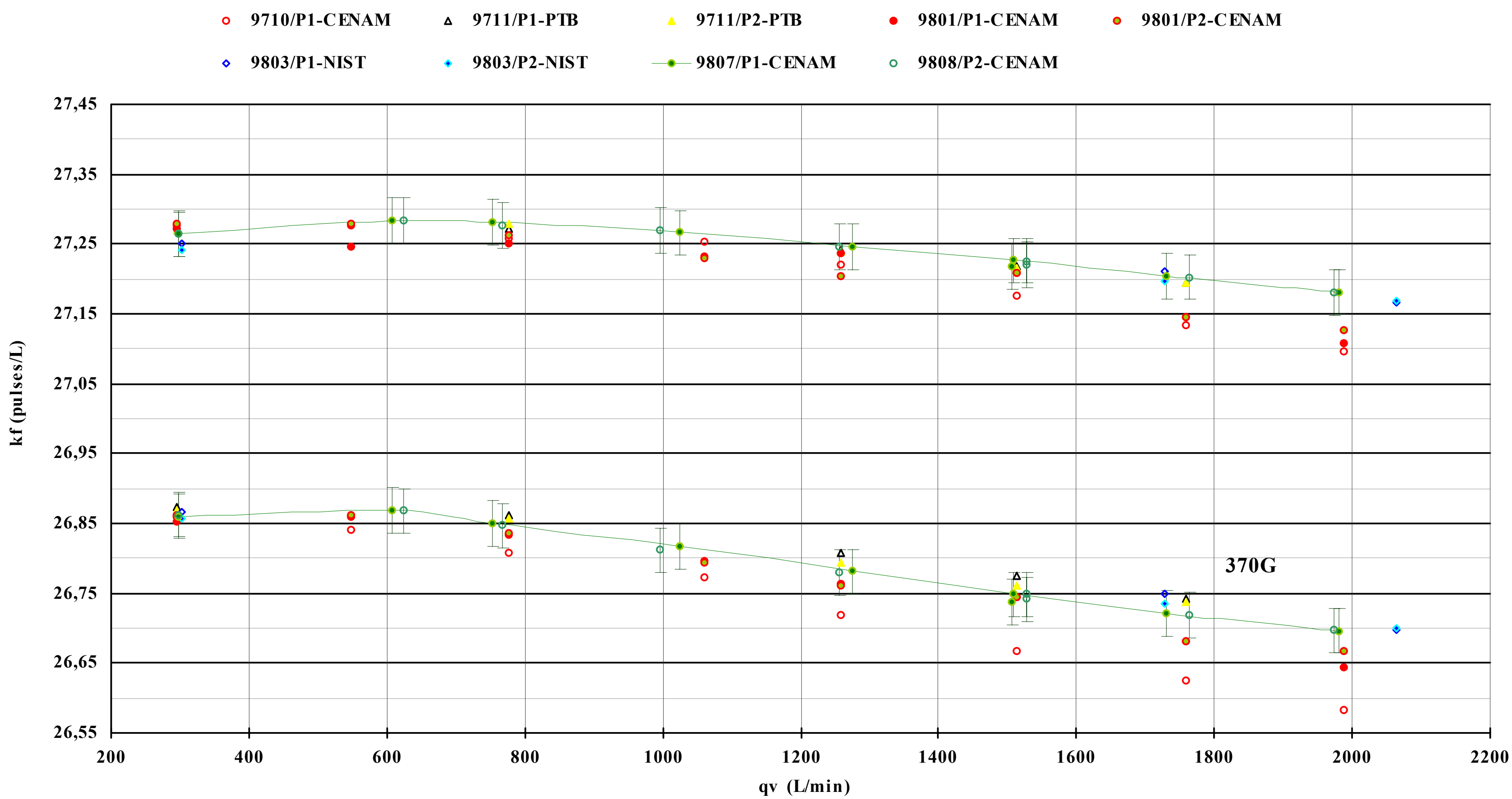
3. Reference laboratories were not requested to provide detailed uncertainty analysis. CENAM´s liquid flow laboratory was used the Guide to the Expression of Uncertainty in Measurement –1993.

4. Results

Table 2. Average K factor – flowrate. Upstream meter 367G / Downstream meter 370 G.
Smith Meter Inc. Turbine Meters, DN80 ANSI 300
Tandem Test Configuration I

	CENAM (Nov97)		**PTB** (Nov/97)				**CENAM** (Dic/97-Jan/98)			
qv	P1		P1		P2		P1		P2	
(L/min)	*K factor (pulses/L)*									
295	26,859 3	27,277 7	26,872 6	27,275 6	26,869 8	27,268 8	26,852 8	27,270 8	26,862 8	27,279 6
549	26,840 2	27,276 2					26,860 4	27,245 7	26,862 7	27,279 6
776	26,808 5	27,257 1	26,861 9	27,272 6	26,856 3	27,278 0	26,834 7	27,250 7	26,836 7	27,262 3
1 062	26,773 4	27,254 0					26,795 5	27,231 4	26,794 3	27,228 8
1 258	26,718 1	27,219 8	26,807 4	27,240 9	26,794 0	27,239 1	26,763 5	27,236 0	26,760 6	27,203 6
1 513	26,667 4	27,175 0	26,775 8	27,216 8	26,761 4	27,215 5	26,743 9	27,207 5	26,743 9	27,207 5
1 758	26,623 9	27,132 5	26,741 2	27,195 4	26,736 6	27,194 5	26,682 1	27,144 6	26,682 1	27,144 6
1 988	26,582 0	27,096 1					26,643 8	27,108 6	26,667 9	27,126 4

	NIST (March/98)					**CENAM** (July-August/98)			
qv	P1		P2		qv	P1		P2	
L/min)	*K factor (pulses/L)*								
302	26,866 3	27,251 2	26,8571	27,242 5	298	26,860 4	27,263 7	26,862 5	27,263 8
					616	26,868 9	27,284 0	26,867 8	27,284 4
					761	26,850 2	27,280 9	26,846 6	27,277 2
					1 011	26,817 3	27,266 0	26,811 8	27,269 7
					1 265	26,781 0	27,245 8	26,779 7	27,246 6
					1 518	26,748 7	27,226 2	26,748 1	27,226 1
1 727	26,750 2	27,210 5	26,734 2	27,196 9	1 746	26,721 3	27,204 5	26,718 4	27,202 6
2 064	26,697 4	27,167 0	26,699 4	27,168 6	1 977	26,695 7	27,181 6	26,696 8	27,180 2
					1 518	26,737 1	27,218 4	26,741 0	27,220 3

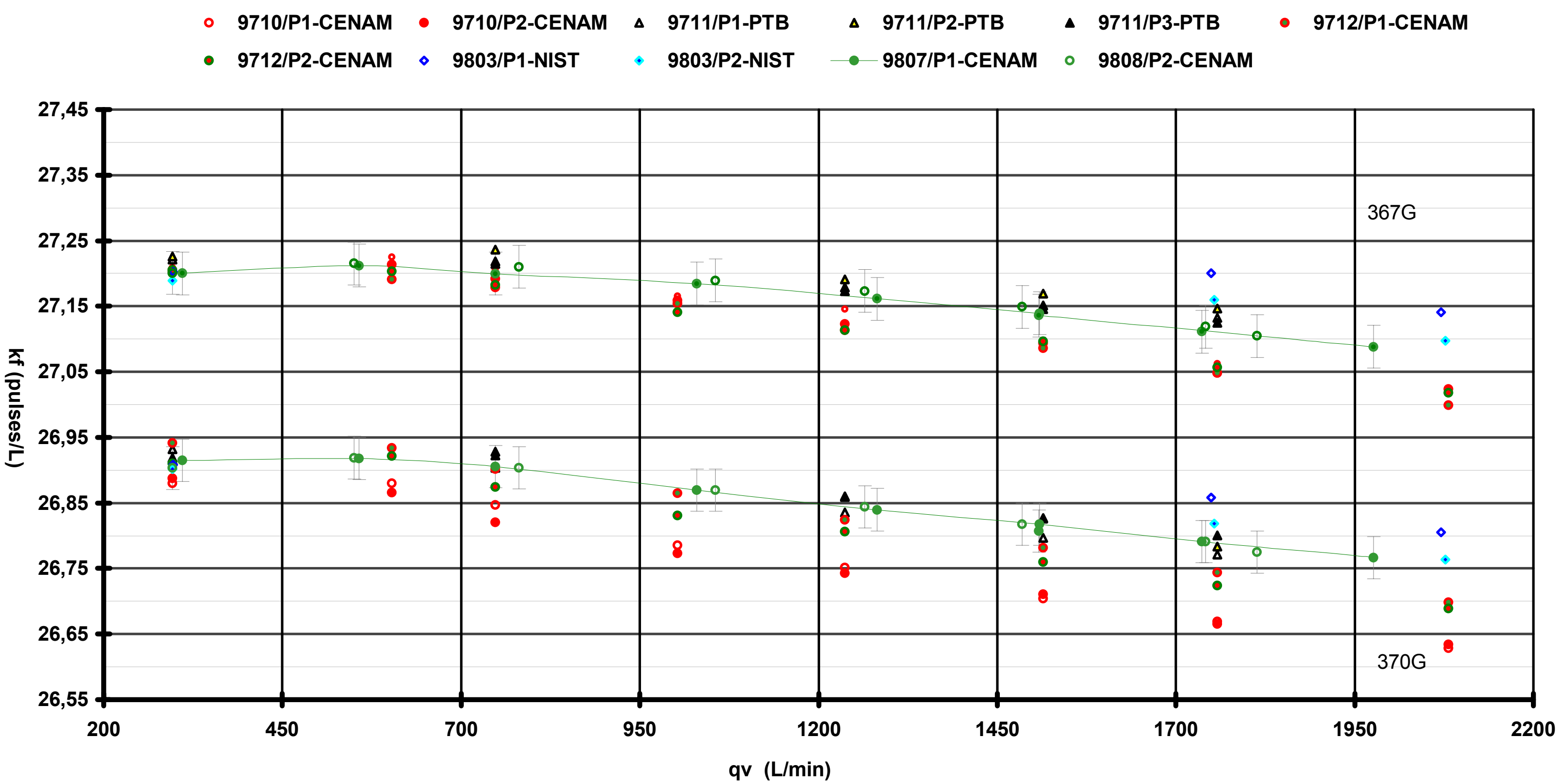


Graph 1. Average K factor – flowrate. Upstream meter 367G / Downstream meter 370 G.
Smith Meter Inc. Turbine Meters, DN80 ANSI 300
Tandem Test Configuration I, L/D = 20.

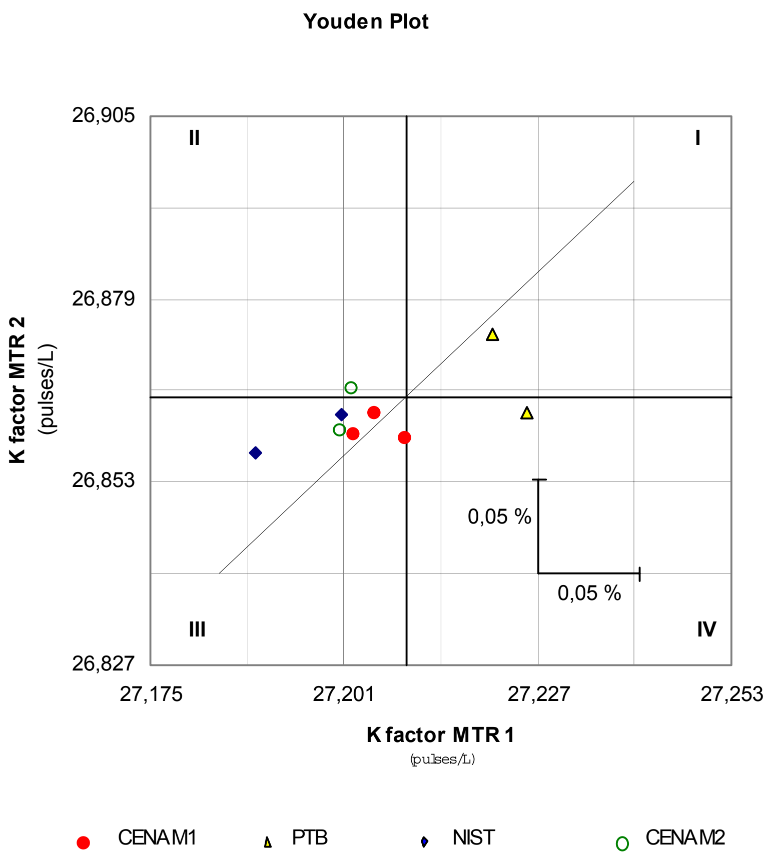
Table 3. Average K factor – flowrate. Upstream meter 370G / Downstream meter 367 G.
Smith Meter Inc. Turbine Meters, DN80 ANSI 300
Tandem Test Configuration II

qv (L/min)	**CENAM** (Oct 97)				**PTB** (Nov 97)						**CENAM** (Dic-97/ Jan 98)			
	P1		P2		P1		P2		P3		P1		P2	
	K factor (Pulses/L)													
296	26,879 6	27,209 0	26,887 4	27,205 3	26,931 9	27,220 8	26,915 5	27,226 0	26,918 9	27,206 2	26,941 6	27,202 3	26,910 6	27,204 9
603	26,880 3	27,224 8	26,866 1	27,213 7							26,933 5	27,191 1	26,921 5	27,203 3
748	26,8471	27,206 0	26,820 5	27,191 5	26,903 2	27,218 1	26,927 7	27,236 0	26,922 1	27,214 9	26,901 5	27,178 7	26,874 0	27,182 5
1 003	26,785 0	27,165 8	26,773 6	27,158 8							26,864 4	27,153 9	26,831 2	27,141 3
1 237	26,751 4	27,145 2	26,742 5	27,122 5	26,835 9	27,178 3	26,859 2	27,191 2	26,860 4	27,173 4	26,824 1	27,113 4	26,806 5	27,113 6
1 514	26,704 6	27,094 7	26,710 6	27,093 2	26,797 2	27,151 2	26,826 3	27,169 1	26,826 8	27,145 9	26,781 2	27,086 2	26,759 7	27,096 7
1 758	26,669 5	27,062 6	26,665 1	27,047 9	26,771 0	27,132 3	26,783 9	27,146 7	26,800 3	27,125 0	26,744 0	27,048 3	26,724 1	27,056 6
2 082	26,628 6	27,023 0	26,634 2	27,023 7							26,698 3	26,999 1	26,688 7	27,017 5

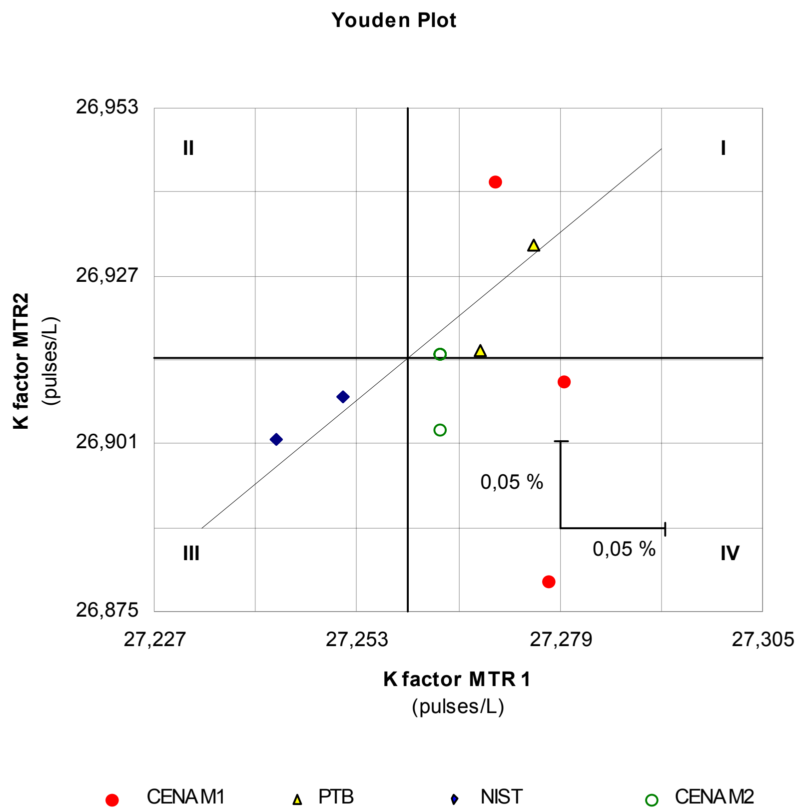
qv (L/min)	**NIST** (March 98)				**CENAM** (July – August 98)					
	P1		**P2**		**qv**	**P1**		**qv**	**P2**	
	K factor (Pulses/L)									
297	26,908 2	27,202 0	26,901 7	27,189 0	310	26,914 9	27,200 3	296	26,903 2	27,200 6
					557	26,917 6	27,212 0	550	26,919 0	27,215 3
					748	26,905 3	27,199 7	781	26,903 3	27,210 3
					1 029	26,869 7	27,184 5	1056	26,869 3	27,189 4
					1 282	26,839 7	27,161 5	1265	26,844 2	27,173 1
					1 509	26,817 3	27,139 3	1485	26,817 6	27,149 2
1 749	26,857 8	27,200 6	26,818 8	27,159 8	1 736	26,791 1	27,111 1	1741	26,790 6	27,118 9
2 071	26,805 2	27,140 5	26,763 7	27,097 3	1 977	26,766 1	27,088 3	1814	26,775 2	27,104 5



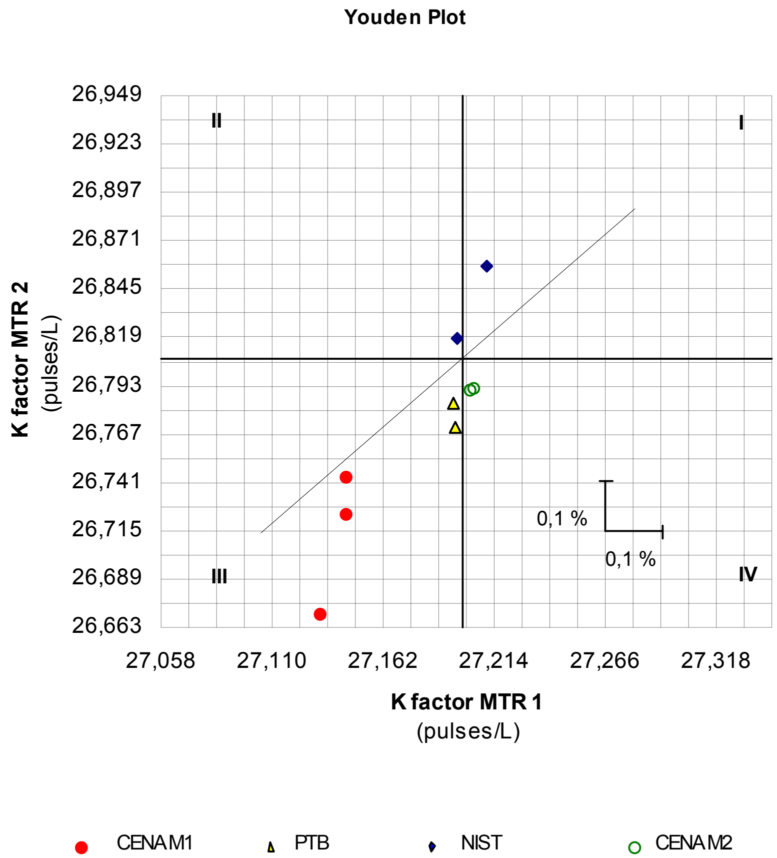
Graph 2. Average K factor – flowrate. Upstream meter 370G / Downstream meter 367 G
Smith Meter Inc. Turbine meters, DN80, ANSI 300
Tandem Test Configuration II, L/D = 20



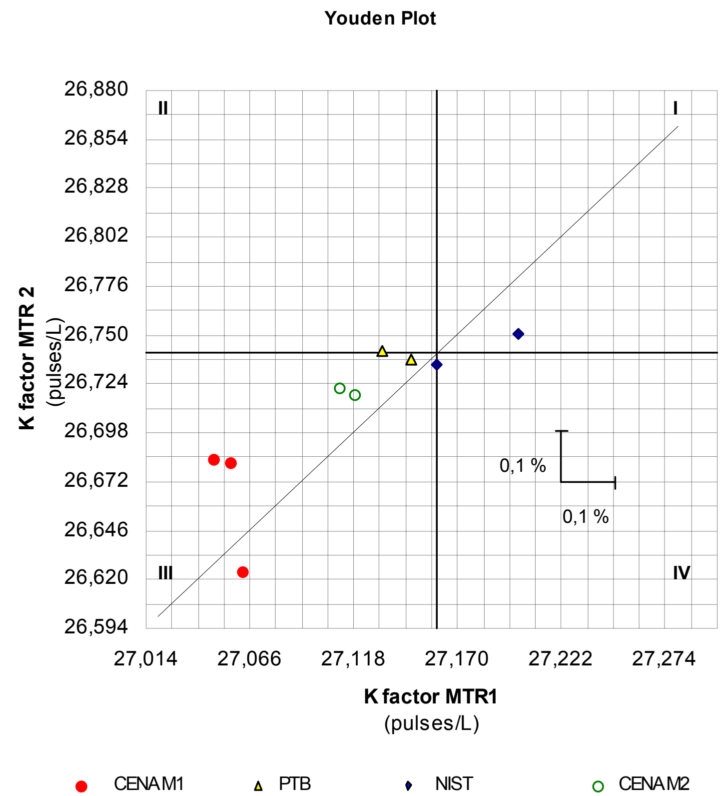
Graph 3. Downstream Meters – Low Flow (300 L/min).



Graph 4. Upstream Meters – Low Flow (300 L/min).



Graph 5. Downstream Meters – High Flow (1 740 L/min).



Graph **6.** Upstream Meters – High Flow (1 740 L/min).

Conclusion

- Turbine 370 G exhibited a significant change in meter factor ("before -0,44 % and after - 0,24 %"). It is supposed that this change was due to the fact that this turbine meter was new and did not run enough to overcome bearings' friction.

- When the second phase was completed, CENAM analyzed the results by means of the Youden Method.

- This type of comparison is suitable to produce a realistic Confidence in liquid flow measurement for the participating laboratories. However, More such comparisons are necessary to complete a full assessment of the measurement systems.

- This program should be expanded to include additional *national standard laboratories to incorporate different types of calibration facilities.*

Acknowledgments

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